EFFECTS OF LEG GIRTH AND LEG LENGTH ON DIVISION I TRACK ATHLETES RACE PERFORMANCE

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by

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Track and field coaches look at runners and try to determine at what event they would perform best; decisions that can partially be based on the runner’s body type. The purpose of this research was to determine if there were certain characteristics of leg size of NCAA Division I track athletes, which could be used to focus training efforts to certain race distances. Subjects (n = 23) were members of the Men’s and Women’s Morehead State Cross Country and Track teams. Subjects completed a short questionnaire and had leg girth and length measurements taken using a Gulick tape measure. Personal bests in race performances were collected from 800m-5000m of each subject. For both sexes, thigh-calf girth ratios showed no significant correlations between the tested races distances (800m-5000m). A significant correlation was found for subjects’ upper-lower leg length and performances in the 800m (Males: $r = 0.60$, $r^2 = 0.36$, $p < 0.05$; Females: $r = 0.58$, $r^2 = 0.34$ $p < 0.05$). Males showed positive correlations for thigh and calf girth measurements separately for the 5000m (Thigh: $r = 0.74$, $r^2 = 0.55$, $p < 0.01$;

Calf: $r = 0.57$, $r^2 = 0.33$ $p < 0.05$) as well as combined thigh+calf ($r = 0.73$, $r^2 = 0.53$, $p < 0.01$) and thigh+calf/upper+lower ($r = 0.69$, $r^2 = 0.48$, $p < 0.01$). The findings of this study were consistent with the results of other studies. This study found that upper-lower leg length ratio may be a good indicator of performance in the 800m race. Potential success at the 5000m race distance can also be determined through these leg measurements. A larger population should be included in future studies.

Accepted by: ______________________________, Chair

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Chapter 1 Introduction

There are many different body types for runners. Many coaches examine a runner’s body type in an effort to classify at which event they would best perform. Middle distance runners, which vary from 800m to 3000m, are typically characterized as having a tall, muscular build. Runners that specialize in long distances, 5000m to 10000m or longer, typically have leaner, smaller builds. East African runners, who have dominated the international long distance running scene for decades, are characterized with lean, less muscular bodies and having skinny looking calves. Some research indicates that the East African runners’ skinnier legs produce a lower moment of inertia which contributes to their dominance in long distance running (Kong & Heer, 2008; Foster, Lucia, Esteve-Lanao, & Chelstrom, 2008). Long distance runners have been characterized as long-legged while shorter distance runners, or sprinters, are characterized with shorter proportional leg length (Malina, Harper, & Avent, 1971).

However, some prominent runners break away from these stereotypes. For example, the 2012 Silver medalist in the men’s 1500m, Leo Manzano, is relatively short for his event (5’5” tall), but still excels at the event (USATF, 2016). On the other end of the spectrum American runner, Chris Solinsky excels at the longer distances. He is best known for being the first American to run the 10000m under 27 minutes (26:59.60) (USATF, 2016). Running economy can be influenced by many different anthropometric, biomechanical, and physiological factors of a runner (Saunders, Pyne, Telford, & Hawley, 2004; Scholz, et al, 2008). Research has found that males with average or slightly less than average height tend to have better running economy, and females of slightly greater than average height tend to have a better running economy (Anderson, 1996). Solinsky, stands out from other runners in the event due to his larger more muscular build. This suggests that there may not be a set body type for runners in specific events.

There has been extensive research that indicates that race performance may be predicted by a runner's lower body anthropometric measurements (Foster, et al, 2008; Kong & Heer 2008; Bale, Bradbury, & Colley, 1986; Bale, Bradbury, & Colley, 1985; Schmid, et al, 2012).

Coaches for cross country and track and field have inconclusive research on if there is an ideal body type of runners. The most common method for determining training strategies for runners is previous race performances in particular events. Coaches may find it useful to be able to train athletes when they know that they have a better chance at excelling in a specific event. Studying leg girth and leg length ratio measurements could provide further insight on future running success. The focus of this study was to determine if there is a correlation between an athletes' Personal Records (PR) in events ranging from 800m-5000m and their thigh-calf ratio (T:C) and upper-lower leg length ratio.

Problem Statement

- To determine if there is was correlation between the thigh-calf girth ratio and upper-lower leg length ratio and race performance in events from 800m-5000m.

Hypothesis

- H_0-Race performance, in time, in 800m-5000m events are not related to thigh-calf girth or upper-lower leg length.

- H_a-Race performance, in time, in 800m-5000m events are related to thigh-calf girth or upper-lower leg length.

Operational Definitions

- Personal Record (PR)- A runner's best performance (Time) in an event. May also be referred to as a personal best (PB).
- Anthropometric- Measurement of human body, specifically for this study the thigh and calf girths, and upper and lower leg lengths.
- Cross Training- Any form of moderate intensity exercise other than running, for example swimming, aqua jogging, elliptical training, etc.…
- Running Economy(RE)- Necessary oxygen consumption and energy expenditure required to maintain a given velocity or pace. The efficiency of a runner.
- Slim Physiques- Relative term to the sampled population. Interchangeably referred to as 'smallness', or slim limbs.

Delimitations

- Only NCAA Division I track & field athletes were used for data collection in the study.
- Athletes must have participated in at least one Track and Field season for their university to be tested.
- Athletes must have refrained from any moderate intensity exercise, such as running, resistance training, or cross training before testing. They must have had a minimum of 8 hours'-recovery before testing.
- Athletes must have been consistently training and completed their coaches training recommendations for at least one month prior to testing.

Limitations

- Reported race times could have been falsified or misreported by the individuals tested in the study.
- Sample size was limited to one university cross country and track team.

Assumptions

- All measurements were taken at the same location from person to person.
- The reported race times on the questionnaires were an accurate representation of the athletes' race ability, and that the data was not misreported.
- Subjects have not performed any moderate intensity exercise within 8-hours of measurement.
- The sample from this study was not an outlier from other NCAA Division I universities, and other universities would follow the same trends as found in this study.

Significances of the Study

- If the hypothesis is correct, then measurements of an athlete's thigh-calf girth ratios or upper-lower leg length ratios could help coaches and athletes focus training efforts toward a specific event that they have determined the athletes will have the best race results in. For example, if the research finds that a specific thigh-calf girth or upper-lower leg length ratio correlates with faster race performances in a certain race distance then the coach and athlete could focus training towards that event. Some equipment used to analyze physiological variables may be not be available to all coaches and athletes and this study could be a source of easy assessment of a runners ability to perform at a certain distance race.

Chapter 2 Review of Literature

To date there has been little to no research conducted specifically comparing thigh and calf girth ratios to running performances or the upper-lower leg length ratios. However, several studies have shown correlations to anthropometrics measurements of the legs and an athlete's running performance (Bale, et al, 1985; Bale, et al, 1986; Dellagrana, Guglielmo, & Santos, 2015; Foster, et al, 2008; Kong & Heer 2008; Schmid, et al, 2012). Another influence to running performance is an athlete's physiology, specifically running economy (Foster, et al, 2008; Millet, et al, 2002; Paavolainen, et al, 1985), and VO_{2max} (Barnes, et al, 2014; Dellagrana, et al, 2015; Lucia, et al, 2006; Tanaka & Matsuura 1981). Coaches may find it useful to be able to train athletes when they know that they have a better chance at excelling in a specific event. Studying leg girth and leg length measurements could provide further insight on potential running success.

Physiological Determinants of Race Performance

Running economy is considered one of the most accurate ways of predicting performance in endurance events. Running economy is the necessary oxygen consumption and energy expenditure required to maintain a given velocity. In other words, how efficient a runner is at a given pace. It has been known for years that running economy accounts for a large variation in race performance, especially as the race distance increases (Conley, & Krahenbuhl, 1980). Conley, et al (1980), studied 12 male subjects (n = 12) in a 10km time trial. 65.4% of the variation in time trial performances was explained through running economy ($r^2 = 0.65$).

Running economy can have various anthropometric, biomechanical, and physiological influences, as shown in two studies which reviewed the influences of running economy (Scholz, et al, 2008; Saunders, et al, 2004). Both studies analyzed biomechanical and physiological effects on running economy through treadmill testing. Scholz, et al, (2008) studied the various effects on running economy on 15 highly trained male subjects (n =15, Age: 26 ± 7.3 yr, VO_{2max}: 54.86 ± 16.73 ml/kg/min^{-1}). Following treadmill testing, limb length (r = 0.57), Achilles tendon moment arm (r = 0.56), body mass (r = 0.51), and body mass distribution (r = 0.48) showed significant effects on running economy. Saunders, et al, (2004) also studied variables that effect running economy in 16 male runners (n = 16). Following treadmill testing, stride length (r = 0.52), muscle stiffness (r = 0.61), oxidative enzymes (r = 0.59), stride rate (r = 0.49), and foot strike patterns (r = 0.53), all showed significant correlations to running economy. In a separate study, it was found that both leg stiffness (r = −0.80) and moment arm length (r = 0.90) are both highly correlated to running economy (Barnes, McGuigan, & Kilding, 2014). Leg stiffness was measured as the amount of movement of the ankle and knee joints, in degrees, during physical activity, and in this case running (Barnes, et al, 2014).

Several studies have concluded that smaller legs are associated with improved running economy (Foster, et al, 2008; Tanaka & Matsuura 1981; Lucia, et al, 2006). There is conflicting research on whether aerobic training is associated with significant skeletal muscle hypertrophy (Konopka & Harber, 2014; Krustrup, Christensen, Randers, 2010; Trappe, et al, 2006). According to Trappe, et al, (2006), aerobic training may have the opposite effect on longer distance runners. Trappe studied seven marathon runners (n = 7, Males: 4, Females: 3, Age: 22 ± 1 yr, Mass: 68.0 ± 2.0 Kg) over a 13-week training period. Following the 13-week marathon training program emphasizing aerobic training (100% of training volume done at an intensity of

70-75% VO_{2max}), muscle biopsies showed that gastrocnemius muscle size decreased by approximately 20% in both type I and type IIa muscle fiber types. VO_{2max} did not increase significantly ($p > 0.05$), they attributed this to hydration status and submaximal treadmill testing were used. In contrast, a separate study added an anaerobic element to an aerobic training program (15% of training volume done at an intensity of 100-105% of VO_{2max}). Two groups were created, one a control group with all of their training volume at <70% of VO_{2max}, and the other group the experimental. Over a 12-week training program, the group with an anaerobic element added to their training saw a significant increase in muscle lactate removal efficiency (Pre-test: 30.1 ± 4.1 mmol/kg, Post-test: 15.6 ± 3.3 mmol/kg, $p < 0.05$). Muscle fiber size had been seen to increase in quadriceps muscle mass (9% increase) and mean muscle fiber area (15% increase) (Krustrup, et al, 2010). Also noted in the study was that there were physiologic improvements in blood lactate, and muscle lactate levels in the anaerobic based training group. Blood lactate and muscle lactate levels were markers for aerobic and anaerobic threshold. Several studies have shown correlations with improved running economy after anaerobic training along with heavy weight training were added simultaneously to endurance training programs (Paavolainen, Häkkinen, Hämäläinen, Nummela & Rusko, 1985; Millet, Jaouen, Borrani & Candau, 2002). They attribute improved running economy to improved neuromuscular function due to anaerobic training and weight training. Increases in calf size have been correlated with improvements in aerobic testing. Similarly, Yigit and Tuncel (1998) studied male 15-21-year-old high school and college students' aerobic and anaerobic power. Before the training regimen 51 students ($n = 51$) performed a vertical jump test and 12 -minute walk/run test. Nineteen students were assigned the sand training group ($n = 19$), while 14 trained ($n = 14$) on roads and eighteen ($n = 18$) were kept as control. They concluded that after a 6-week endurance training program, those who trained in the sand had a larger increase in calf circumference and had the most significant improvement in a 12-minute run/walk test ($p < 0.05$), r values were not reported in the study. They concluded that through a 6-week sand training program, physiological improvements were greater than the control, non-sand training group. This research showed that there may be a relationship between increases in calf circumference and improved performance in aerobic testing. Through a review of previous research, Van Wessel, et al, (2010) found that there is an inverse relationship between muscle fiber size and the muscles oxidative capacity, leading to what he called the muscle fiber-type paradox. This infers that runners with higher aerobic capacities (type I fibers) should have smaller legs. The more type I muscle fibers someone has the better they should perform in distance running events. Anaerobic training has been shown to produce hypertrophy of muscle tissue and leg size. Larger legs are indicative of more type II muscle fibers, which have less oxidative capacity than type I muscle fibers. Less oxidative capacity indicates slower performances at distance running (Van Wessel, et al, 2010). According to Trappe, et al, (2006), aerobic training has been shown to decrease muscle fiber size by up to 20%, in marathon runners. Anaerobic training, which consisted of fast explosive movements with and without weights, have been shown to produce muscle hypertrophy (Krustrup, et al, 2010). Dellagrana, et al, (2015) studied the physiological and anthropometric variables of young male runners ($n = 23$) and their performances in a 5km time trial. Height, body mass, body fat, and fat-free mass (FFM), maximal oxygen consumption (VO_{2max}), ventilatory threshold, and running economy were all measured during a 5km time trial on a treadmill. Correlation analysis were used to determine the best anthropometric and physiological variables that were significantly related to 5km performance. Analysis had shown 71% of the 5km time trial performances were explained by the participants' lower extremities fat-free mass

($r = 0.84$, $r^2 = 0.71$), and 40% of variance in 5km time trial performances were explained through ventilatory threshold ($r = 0.63$, $r^2 = 0.40$). They concluded that strength and muscle power are not good indicators of 5km time trial performance, instead the more accurate variable to use to predict performance comes from the physiological and anthropometric measurements ($p < 0.05$). The correlation shown between FFM and 5km time trial performance ($r = 0.84$) indicates that smaller leg mass is related to improved 5km race performances (Dellagrana, et al, 2015).

Leg length has been shown to be among the multiple variables affecting running economy. Laumets, et al. (2017) studied anthropometric measurements of elite male European runners ($n = 13$), anthropometric measurements were taken using a Duel-energy X-ray absorptiometry (DEXA) scan procedure. Lower leg length and running economy were compared at speeds of 14, 16, and 18 $km \cdot h^{-1}$. Correlations between lower leg length and running economy were, 14 ($r^2 = 0.27$; $p < 0.08$); 16 ($r^2 = 0.32$; $p < 0.05$) and 18 ($r^2 = -0.303$; $p = 0.05$) $km \cdot h^{-1}$. Mean and standard deviations were calculated for: upper leg length (43.5 ± 3.1 cm), lower leg length (47.8 ± 2.8 cm), total leg length (91.3 ± 4.4 cm), thigh girth (52.2 ± 1.6 cm), and calf girth (36.7 ± 1.3 cm). They concluded that lower leg length had an inverse relationship with a runner's running economy, where running economy was more efficient with subjects that had shorter lower leg lengths. Lucia, et al, (2006) studied physiological and anthropometric differences of Eritrean and European runners showed that maximal calf circumference (30.9 ± 1.5 cm vs. 33.9 ± 2.0 cm, $p < 0.01$) was lower in the Eritrean runners than the European, as well as their lower leg length (44.1 ± 3.0 cm vs. 40.6 ± 2.7 cm, $p < 0.05$). VO_{2max} values did not differ significantly, however running economy differed between the two groups when run at 21km/hr (Eritreans: 65.9 ± 6.8 mL.kg-1.min-1 vs. Europeans: 74.8 ± 5.0 mL.kg-1.min-1), ($p < 0.01$). They concluded that the Eritrean runner's superior running economy is associated, at least partially, with the measured anthropometric variables. They suggest that running economy, which is associated with lower leg length and calf circumference, contributes significantly to East African distance running success. (Lucia, et al, 2006).

Many regression equations exist that combine anthropometric and physiological measurements. Rhodes and McKenzie (1984) measured anaerobic physiology in a study on 18 male subjects running at their Anaerobic Threshold (AT), which they determined by examining the excess CO_2 elimination curve. By analyzing the speed at which a subject reached their AT, they could predict marathon times within 2 minutes of the actual personal best time in that event ($r = 0.94$, $p < 0.01$), no equation that was published could be found. Kenney and Hodgson (1985), AT in Olympic 5000m and 3000m steeplechase athletes. They conducted a treadmill test and found that the anaerobic threshold and age of a 5000m runner were the two best predictors of 5000m race performance. They created a regression equation for 5000m race performance: 5000m race time = 1155 - 5.4 (age) – 2.9 (AT ml/kg/min^{-1}). In the 3000m steeplechase Olympians, anthropometric measurements showed 94% ($p < 0.05$) of the variation in race performance. The addition of the AT of athletes increased the r^2 value to 98% ($p < 0.05$). The regression equation for 3000m steeplechase race performance was: 3000m steeplechase = 99 + (weight) + 0.6 (AT ml/kg/min^{-1}).

Anthropometric Determinants of Running Performance

Several studies found that smaller leg circumference correlates with race performance in longer distances (Bale, Bradbury, & Colley, 1985; Bale, Bradbury, & Colley, 1986; Foster, et al, 2008; Kong & Heer 2008). Kong and Heer (2008), studied six (n = 6) elite NCAA collegiate Kenyan runners (Age: 22.0 ± 1.8yr) The runners of this study were characterized by low BMI (20.1 ± 1.8 kg·m- 2), low body fat percentage (5.1 ± 1.6%), and small calf circumference (34.5 ±

2.3 cm). Calf circumference was measured at the point of largest circumference between the knee and the ankle, leg length was measured from the greater trochanter to the lateral malleolus. Kong and Heer (2008), concluded that the slim limbs of the Kenyan runners may contribute to their performance by providing a lower moment of inertia. A body with lower moment of inertia will rotate faster than a body with higher moment of inertia, in this case the body is the lower extremity. Slim limbs will produce a lower moment of inertia, thus allowing the runners less muscular effort to swing their legs. Less muscular effort improves running economy, making the body more efficient at long distance running. Kong and Heer (2008), also had shown that short ground contact time is correlated to improved running performance, foot-to-ground contact time is related to running economy. Shorter ground contact time can be attributed to mid-foot or fore-foot striking pattern which is consistent with more economical runners since there is less braking force to deaccelerate forward motion of the body. Body mass and shape have been seen as key contributing factors to successful runners. Slender legs, running economy, and muscle fiber type ratios have been attributed to the success of East African runner's (Larsen, 2003). Pedoe, (2000) writes in Marathon Medicine, that elite South African marathoners have an overall smaller body mass than elite North American marathoners. Thigh and calf girth measurements were taken of the South African runners (n = 9, Age: 27.1 ± 3.4yr, Mass: 53.9 ± 3.7 kg) mean thigh girths were calculated to be 46.8 ± 1.8 cm and mean calf girths were 32.6 ± 1.6 cm. The North American runners (n = 20, Age: N/A, Mass: 63.1 ± 4.8 kg) thigh girths were 51.9 ± 2.3 cm and calf girths of 35.4 ± 1.3 cm, significantly larger than the East African runners ($p < 0.05$). The sample of South Africans had an average half-marathon PR of 61.15 ± 0.33 minutes, race times for the North American runners were not published however the sample came from the elite runners of the 1990s and early 2000s. Smaller limb circumferences were attributed as a factor in African runners distance running success over the North American runners.

Many studies have been conducted that have shown that various anthropometric measurements can be used to predict race performance. Knechtle, et al, (2011) studied race performances of athletes ($n = 81$) in an Iron Man competition. Skinfold measurements and limb circumference were measured, sum of 8 skinfolds had a significant correlation ($r = 0.43$). All other anthropometric measurements had no significant correlations in predicting race performance ($r < 0.40$). However, the thigh ($r = 0.18$) and calf ($r = 0.21$) girth measurements had a higher correlation with race time in relation to the running portion of the iron man than other anthropometric measurements taken, which included leg length ($r = 0.07$), arm length ($r = 0.04$), body mass ($r = 0.14$), and body height ($r = 0.14$). It was concluded that personal best times were the best predictors of performance in an ironman triathlon ($r = 0.59$) and a triple iron triathlon ($r = 0.82$). Similar studies focused on male 10k runners ($n = 60$) (Bale, Bradbury, & Colley, 1986) and female marathoners ($n = 36$) (Bale, Rowell, & Colley, 1985) both studies concluded that some of the best predictors for their respective race distances was total training load, previous race performances, and slim physiques relative to the sampled population. Five-site skinfold measurements (suprailliac, subscapular, bicep, tricep, medial calf), as well as calf girth, upper arm girth, and body height were used to calculate slim physiques within the population. Athletes with faster PR’s had slimmer physiques than other athletes in the study (Mean total skinfold elite group: 24.6 cm, mean total skinfold non-elite group: 29.4 cm, $p < 0.05$). Significance was reported at 0.05, no r values were reported in those studies. Similar studies were conducted on ultramarathon runners (Knechtle, Knechtle, Schulze, & Kohler, 2008; Knechtle, Knechtle, & Rosemann, 2010). Ultramarathons, or ultra-endurance races are defined as races covering more than the traditional marathon distance of 26.2 miles. Knechle, et al (2010) studied multiple factors of male ultra-marathon runners (n = 169). They measured upper arm circumference (r = 0.26), Body Mass Index (BMI) (r = 0.29), percent body fat (r = 0.45) total training volume (r = -0.43), training speed (r = -0.56), and age (r = 0.24). Using stepwise multiple regression, a prediction equation was created. It had shown that combining training speed, training volume, and age was able to predict 100km performances: 100-km race time (min) = 1085.60 - 36.26 x (training speed, km/hr.) - 1.43 x (training volume, km/wk.) + 2.50 x (age, yr.). No regression equation was generated using anthropometric variables. Knechtle, et al, (2008) conducted a study that analyzed anthropometric measurements of ultra-marathon runners (n = 19) following a 17-day ultra-endurance event. Limb length and circumference measurements were taken with a Gulick tape measure, all measurements were taken 8-hours following the conclusion of the ultra-endurance race. It was found that upper arm circumference measurements were positively associated with race performance in this type of long distance race ($p < 0.05$, $r^2 = 0.26$). There were no other significant results in other anthropometric measurements taken which included: body height, body mass, average skin-fold thickness limb length, and the circumference of thigh and calf alone ($p > 0.05$). A similar study involving female marathon runners following a marathon race was conducted. Schmid, et al, (2012) showed that body mass (r = 0.37), body mass index (r = 0.46), thigh circumference (54.1 ± 3.5cm) (r = 0.51), calf circumference (36.2 ± 2.0cm) (r = 0.41), and training speed (9.7 ± 1.4km/h) (r = -0.61) were all correlated to faster marathon racing times in females ($p < 0.05$). Marathon race time may be predicted using calf and training speed measurements through the following equation: Race time (min) = 184.4 + 5.0 x (circumference calf, cm) -11.9 x (speed in running during training, km/h). This study shows that leg anthropometry, specifically of the thigh and calf, can positively influence marathon distance running. Knechtle, et al (2008) study on ultra-marathon events concluded that race further than the marathon distance may be correlated to other anthropometric measurements other than the leg, for example the arm, leg length, skinfolds, or height. Longer limb length in proportion to the upper body has been correlated to improved running performance. The University of Wisconsin La-Crosse (Foster, et al, 2008), studied general body size for various athletes, including east African runners, European runners and larger American football players. Anthropometric measurements were taken from height, body mass, BMI, calf girth, thigh girth, leg length and proportional leg length. Although none of the r^2 values were very strong in relation to cost of running: height ($r^2 = 0.11$), body mass ($r^2 = 0.38$), BMI ($r^2 = 0.31$), calf girth ($r^2 = 0.31$), thigh girth ($r^2 = 0.28$), leg length ($r^2 = 0.10$) and proportional leg length ($r^2 = 0.30$), the researchers concluded that in the sampled population, runners that were described as slim or smaller than the other runners sampled had faster PR's. Body mass, BMI, calf girth, thigh girth, and proportional leg length were all significant ($p < 0.05$). A moderate correlation was shown for PR's and longer leg length in relation to the upper-body ($r = 0.55$). Thigh ($r = 0.53$) and calf ($r = 0.56$) girth both showed similar correlations, slimmer legs were associated with faster race performances.

Both Foster, et al (2008) and Barnes, et al (2014) had similar conclusions that no single anthropometric measurement can be used to explain a runner's race performance, but rather it is probably the sum of a combination of multiple lower-body attributes. The researchers of those studies recommended future studies to analyze combinations of anthropometric measurements. Tanaka and Matsuura (1981) measured VO_{2max} and various anthropometric measurements on 119 male Japanese runners (age = 19.0 ± 1.7 yr). The subjects 800m, 1500m, and 5000m race performances were best related to chest girth ($r^2 = 0.40$), upper leg length ($r^2 = 0.42$), and thigh girth ($r^2 = 0.50$), 40-50% of variance was accounted for through these measurements, smaller circumference measurements were associated with improved race times. The physiological measurement, VO_{2max}, accounted for 40% of variance of race performance ($r^2 = 0.40$). They concluded that anthropometric attributes could predict distance running performance to the same degree or better than the physiologic measurement, VO_{2max}. Slim physiques (smaller circumference measurements of the chest, thigh, and calf) were associated with faster race times as well.

A review of the literature seems to show that slim physiques, specifically slim legs are good indicators of race performance at longer distances (Bale, et al, 1985; Bale, et al, 1986; Foster, et al, 2008; Kong & Heer 2008). The research is inconclusive as to whether increases or decreases of the fat free mass of thigh or calf circumference is correlated with improved running performance. Increases in aerobic training have been correlated with decreased muscle fiber size (Van Wessel, et al, 2010), however when anaerobic elements are added, muscle hypertrophy may occur (Krustrup, et al, 2010; Yigit & Tuncel, 1998). Running economy and the anaerobic threshold of a runner were also concluded as the best indicators of race performance, however many physiological (lactate threshold, muscle enzyme activity, genetic makeup, muscle fiber type ratio, etc.), anthropometric (limb length measurements, skinfolds, limb girth measurements, body mass distribution, etc.), and biomechanical (strides rate, stride length, foot strike pattern, ground contact time, etc.) characteristics factor into running economy and anaerobic threshold (Barnes, et al, 2014; Paavolainen, et al, 1985; Foster, et al, 2008; Lucia, et al, 2006; Millet, et al, 2002; Tanaka & Matsuura 1981). It appears that no single anthropometric measurement can be used to predict race performance. However, many studies reviewed indicated that it may be possible to use multiple anthropometric measurements to predict race performance in distance runners. The research is lacking on comparisons of thigh-calf girth and upper-lower leg length ratios to race performance. Therefore, a combination of leg girth and leg length measurements may be able to predict race performance in 800-5000m runners.

Chapter 3 Methods

The study was approved by the Morehead State University IRB committee prior to implementation. This was a cross-sectional study. All subjects (n = 23, Male: n = 12, Female: n = 11) of the study were recruited from the Morehead State University Men's and Women's Cross Country and Track teams, both NCAA Division I sports. The Head Coach for the program was contacted prior to testing in order to obtain permission to test his athletes. Subjects were delimited to those who had been consistently training (healthy and full training load for at least one month) and had participated in one spring track season with the university. Subjects were measured before any workout (moderate physical activity of running, resistance training, or other forms of cross training) that occurred on the day of testing or after an 8-hour rest period between bouts of exercise, as recommended by a previous study (Knechtle, et al 2008). All measurements were taken immediately prior to their designated practice time before any moderate physical activity had occurred. Measurements were taken with a Gulick inelastic measuring tape used for circumference measurements and recorded to the nearest tenth (0.1) of a centimeter (cm). All measurements were taken by the same tester. All measurements were taken on the right side of each subject.

Subjects were informed prior to the study that they were not required to participate and that there would be no consequences for not participating. The subjects signed an informed consent and completed a questionnaire (appendix A) which was kept anonymous. No names were used on the questionnaire. Informed consents were kept separate from the questionnaires and kept confidential. The questionnaire consisted of the subject's Personal Record (PR) for a specific race, ranging from 800-5000m which are traditional race distances for collegiate distance runners. Measurements were taken immediately following completion of the questionnaire.

The measurement site for thigh girth was taken midway between the iliac crest and the proximal end of the patella. Subjects were instructed to be standing with weight equally distributed and feet approximately 10 cm apart. The measurement site for the calf was at the point of largest circumference between the ankle joint and the knee joint (ACSM, 2014). The measurement site for upper leg length was taken from the greater trochanter of the right femur to the midway point between the lateral condyle of the femur and the lateral condyle of the tibia, just above the head of the fibula. The measurement site for lower leg length was taken from the second measuring point of the upper leg length measurement to the lateral malleolus. A previous study measured leg lengths and leg circumferences through the same procedure (Kong and Heer, 2008).

Prior to analysis, race times were converted to total seconds and all anthropometric measurements were reported in centimeters. All anthropometric measurements including combinations of measurements were calculated and paired with their PR's over 800m, 1500m, 3000m, and 5000m races. Combinations of anthropometric measurements that were calculated were: thigh-calf ratios (T-C), upper-lower leg length ratios (U-L), thigh+calf (T+C), upper+lower (U+L), and thigh+calf/upper+lower (T+C/U+L). A Pearson's r was used to determine correlations for T-C, U-L, T+C, U+L, and T+C/U+L and PR's over 800m, 1500m, 3000m, and 5000m distances. Statistics were calculated using IBM SPSS Statistics version 21 was used for statistical analysis. The level of significance was set at 0.05 ($p < 0.05$) a priori.

Chapter 4 Results

A total of 23 subjects (12 males and 11 females) agreed to participate in the study. Due to injury or not meeting the training status requirements, 4 males and 4 females were not included in the study. Mean and standard deviations of the subjects ages were calculated (Male: Age: 20.42 $\pm$ 1.00, Female: Age: 19.82 $\pm$ 2.04) Pearson correlations were run on each anthropometric category measured to race times of each subject.

Of the 12 male subjects that participated in the study, 9 reported race times for the 800m, 12 for the 1500m, and 11 for the 3000m and 5000m. Of the 11 female subjects, 10 reported race times for 800m, 11 for the 1500, 9 for the 3000m, and 10 for the 5000m. Tables 1 (pg. 19) and 2 (pg. 19) are basic descriptive statistics of male and female anthropometric measurements and race times in races from 800-5000m.

Pearson Product Moment Correlations were run on all anthropometric measurements (thigh girth, calf girth, upper leg length, and lower leg length), including combinations of measurements (T-C, U-L, T+C, U+L, and T+C/U+L) and race time (800m, 1500m, 3000m, and 5000m) for both male and female subjects. Correlations for male subjects are reported in Table 3 (Table 3, pg.20) and table 4 (Table 4, pg. 21) for female subjects. Significance is reported at the 0.05 level

Table 1: Descriptive statistics of male subjects

	N	Minimum	Maximum	Mean	Std. Deviation
Age (yr)	12	19.00	22.00	20.42	1.00
Thigh (cm)	12	48.00	62.50	53.21	4.08
Calf (cm)	12	30.50	38.50	35.22	2.66
Upper (cm)	12	41.50	46.50	44.08	1.79
Lower (cm)	12	39.50	45.00	42.56	1.78
800m (sec)	9	112.00	124.00	117.78	4.02
1500m (sec)	12	228.00	276.00	246.33	13.43
3000m (sec)	11	503.00	576.00	531.36	21.78
5000m (sec)	11	864.00	988.00	925.27	36.87

Table 2: Descriptive statistics of female subjects

	N	Minimum	Maximum	Mean	Std. Deviation
Age (yr)	11	18.00	23.00	19.82	2.04
Thigh (cm)	11	44.00	55.50	50.98	2.88
Calf (cm)	11	31.00	36.25	34.46	1.72
Upper (cm)	11	38.50	48.50	42.05	2.83
Lower (cm)	11	36.50	43.50	39.41	1.84
800m (sec)	10	138.00	148.00	143.50	3.03
1500m (sec)	11	287.00	338.00	306.09	15.50
3000m (sec)	9	613.00	700.00	658.67	24.42
5000m (sec)	10	1064.00	1172.00	1129.60	29.88

Table 3: Correlation table of anthropometric measurements of male subjects

	800m	1500m	3000m	5000m
Thigh:Calf	r = 0.24 p = 0.27	r = 0.33 p =0.15	r = 0.17 p = 0.31	r = 0.25 p = 0.23
Upper:Lower	r = 0.60 p = 0.05†	r = 0.1 p = 0.38	r = -0.04 p = 0.46	r = -0.31 p = 0.17
Thigh	r = -0.08 p = 0.42	r = 0.17 p = 0.30	r = 0.32 p = 0.17	r = 0.74 p = 0.01‡
Calf	r = -0.30 p = 0.22	r = -0.11 p = 0.37	r = 0.11 p = 0.37	r = 0.57 p = 0.03†
Upper	r = -0.16 p = 0.68	r = -0.30 p = 0.35	r = -0.21 p = 0.54	r = -0.12 p = 0.73
Lower	r = -0.51 p = 0.17	r = -0.35 p = 0.27	r = -0.17 p = 0.14	r = 0.14 p = 0.68
Thigh+Calf	r = -0.19 p = 0.63	r = 0.07 p = 0.84	r = 0.23 p = 0.49	r = 0.73 p = 0.01‡
Upper+Lower	r = -0.34 p = 0.37	r = -0.35 p = 0.27	r = -0.21 p = 0.55	r = 0.01 p = 0.98
Thigh+Calf/Upper+Lower	r = -0.2 p = 0.95	r = 0.25 p = 0.44	r = 0.33 p = 0.33	r = 0.69 p = 0.02†

† statistically significant at $p < 0.05$

‡ statistically significant at $p < 0.01$

Table 4: Correlation table of anthropometric measurements of female subjects

	800m	1500m	3000m	5000m
Thigh:Calf	r = 0.03 p = 0.47	r = -0.06 p =0.43	r = -0.08 p = 0.42	r = 0.03 p = 0.47
Upper:Lower	r = 0.59 p = 0.04†	r = 0.40 p = 0.11	r = 0.36 p = 0.16	r = 0.48 p = 0.08
Thigh	r = 0.02 p = 0.48	r = -0.29 p = 0.20	r = -0.33 p = 0.19	r = -0.28 p = 0.22
Calf	r = -0.01 p = 0.50	r = -0.25 p = 0.23	r = -0.28 p = 0.23	r = -0.32 p = 0.19
Upper	r = 0.33 p = 0.18	r = 0.08 p = 0.41	r = -0.06 p = 0.45	r = 0.33 p = 0.18
Lower	r = -0.10 p = 0.39	r = -0.28 p = 0.21	r = -0.52 p = 0.08	r = -0.02 p = 0.49
Thigh+Calf	r = 0.01 p = 0.49	r = -0.30 p = 0.19	r = -0.35 p = 0.18	r = -0.32 p = 0.19
Upper+Lower	r = 0.17 p = 0.32	r = -0.07 p = 0.42	r = -0.31 p = 0.21	r = 0.21 p = 0.29
Thigh+Calf/Upper+Lower	r = -0.18 p = 0.31	r = -0.18 p = 0.30	r = -0.19 p = 0.32	r = -0.39 p = 0.13

† statistically significant at $p < 0.05$

Male Runners

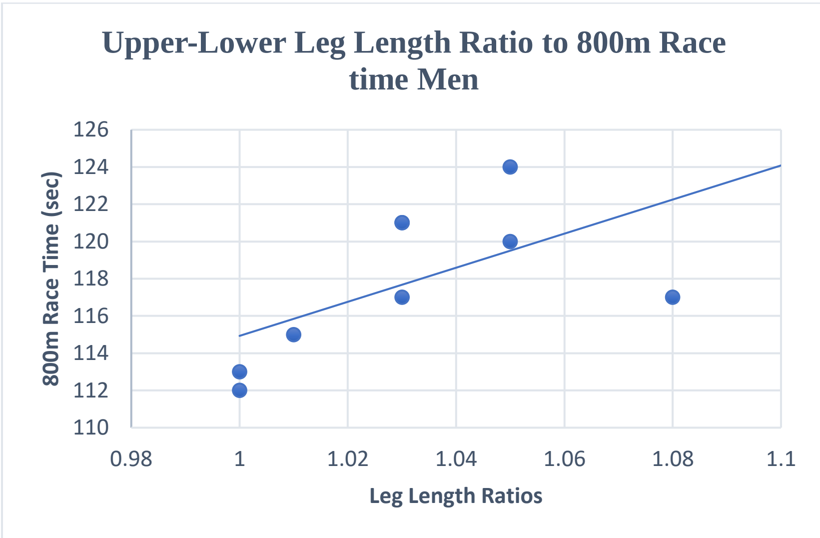
Thigh-Calf girth ratio correlations showed no significant correlations between the tested races distances (800m-5000m) ($p > 0.05$). Correlations for thigh-calf girth ratio were calculated to be as follows, 800m: $r = 0.24$, $p > 0.05$, 1500m: $r = 0.33$, $p > 0.05$, 3000m: $r = 0.17$, $p > 0.05$, and 5000m: $r = 0.25$, $p > 0.05$. A moderate correlation was found between a runner's upper-lower leg length and their performances in the 800m ($r = 0.60$, $r^2 = 0.36$, $p < 0.05$, Graph 1, pg. 23). No other correlation of significance was found between a runner's upper-lower leg length and race performances (1500m $r = 0.10$, $p > 0.05$, 3000m $r = -0.04$, $p > 0.05$, 5000m $r = -0.31$, $p > 0.05$).

Strong and moderate correlations were shown between a runner's thigh and calf girths separately and 5000m race performances. Thigh girth $r = 0.74$, $r^2 = 0.55$, $p < 0.01$ (Graph 2, pg. 23), calf girth correlations were slightly less at $r = 0.57$, $r^2 = 0.33$, $p < 0.05$ (Graph 3, pg. 24). When thigh and calf girth measurements were added together (thigh+calf girths) a strong correlation was found, $r = 0.73$, $r^2 = 0.53$ $p < 0.01$ (Graph 4, pg. 24). Strong correlations were found when thigh and calf measurements were added together divided by the sum of the upper and lower leg lengths [(thigh+calf girths)/(upper+lower leg lengths)], $r=0.69$, $r^2 = 0.48$ $p < 0.01$ (Graph 5, pg. 25). As previous literature suggested, combinations of anthropometric variables may predict race performance in distance runners (Barnes, et al, 2014; Foster, et al, 2008; Tannaka and Matsuura,1981).

No other correlations of significance were found between anthropometric measurements and race times for male runners. One correlation that was not considered significant was found between a runner's lower leg length and race performances in the 800m ($r = -0.51$, $p > 0.05$).

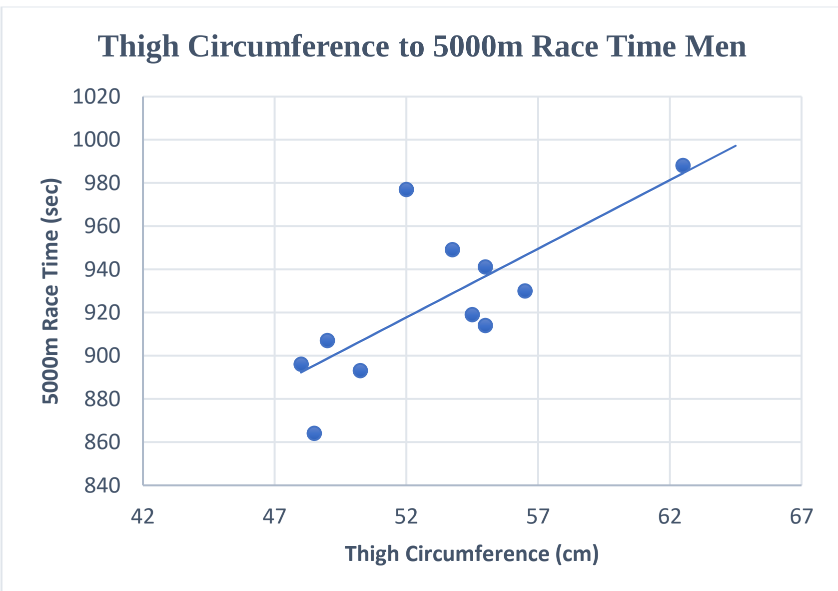
Correlations were found between a runner's race performance over various distances, however that is not the purpose of this study (Table 5, pg. 26).

Graph 1: Male Upper-Lower Leg Length Ratio to 800m Race Performance



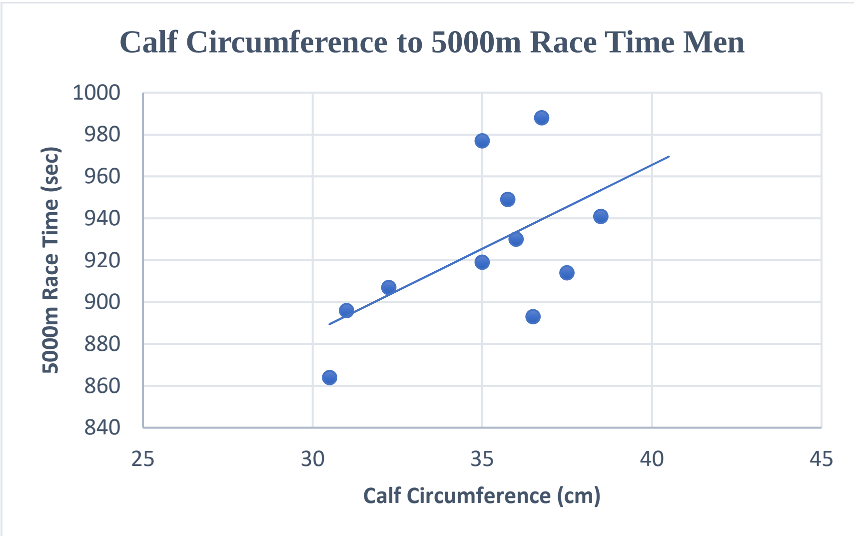
r = 0.60, r^2 = 0.36, $p < 0.05$

Graph 2: Male Thigh Girth Measurements to 5000m Race Performance



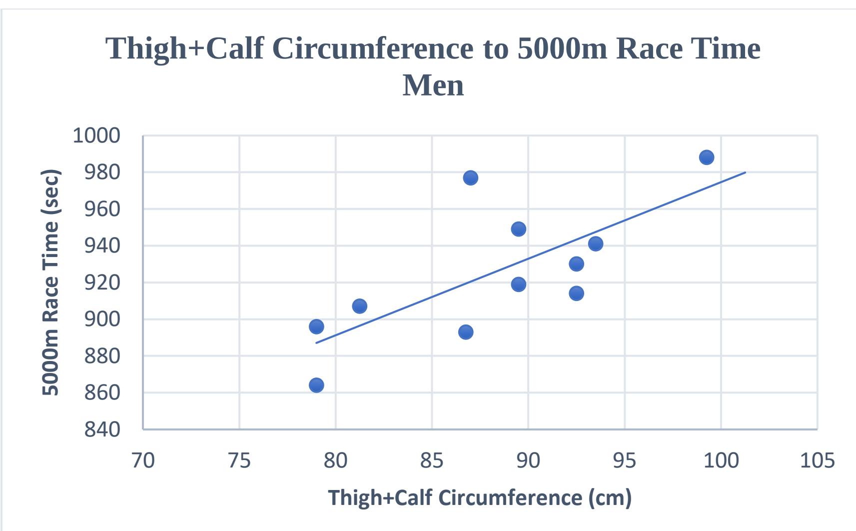
r = 0.74, r^2 = 0.55, $p < 0.01$

Graph 3:Male Calf Girth Measurement to 5000m Race Performance



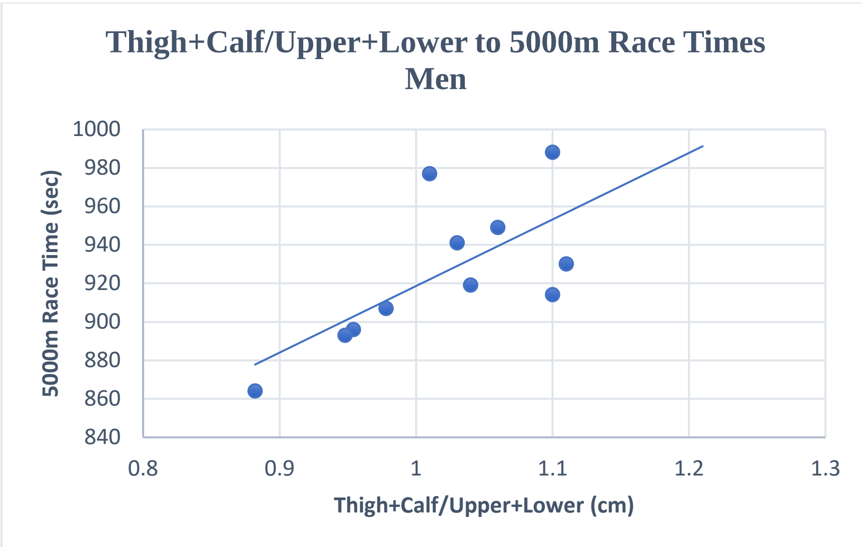
$r = 0.57$, $r^2 = 0.33$, $p < 0.05$

Graph 4: Male Thigh+Calf Girth to 5000m Race Performance



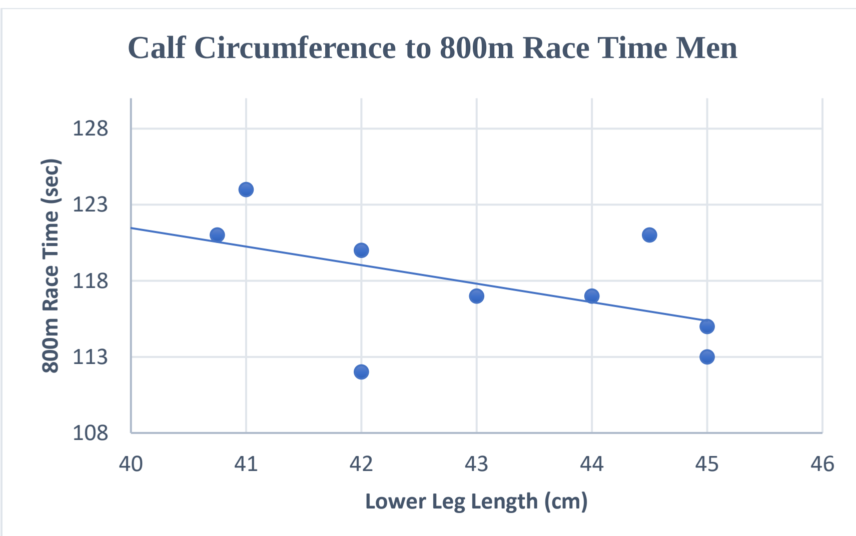
$r = 0.73$, $r^2 = 0.53$, $p < 0.01$

Graph 5: Male Thigh+Calf/Upper+Lower to 5000m Race Performance



$r = 0.69$, $r^2 = 0.48$, $p < 0.01$

Graph 6: Male Lower Leg Length to 800m Race Performance



$r = -0.51$, $r^2 = 0.26$, $p > 0.05$

Table 5: Race time correlations based on other distance race times of male subjects

	800m	**1500m**	**3000m**	**5000m**
800m	N/A	800m-1500m r = 0.83 $p < 0.01$‡	800m-3000m r = 0.75 $p < 0.05$†	800m-5000m r = 0.26 $p > 0.05$
1500m	800m-1500m r = 0.83 $p < 0.01$‡	N/A	1500m-3000m r = 0.94 $p < 0.01$‡	1500m-5000m r = 0.71 $p < 0.01$‡
3000m	800m-3000m r = 0.75 $p < 0.05$†	1500m-3000m r = 0.94 $p < 0.01$‡	N/A	3000m-5000m r = 0.81 $p < 0.01$‡
5000m	800m-5000m r = 0.26 $p > 0.05$	1500m-5000m r = 0.71 $p < 0.01$‡	3000m-5000m r = 0.81 $p < 0.01$‡	N/A

† denotes statistically significant at $p < 0.05$

‡ denotes statistically significant at $p < 0.01$

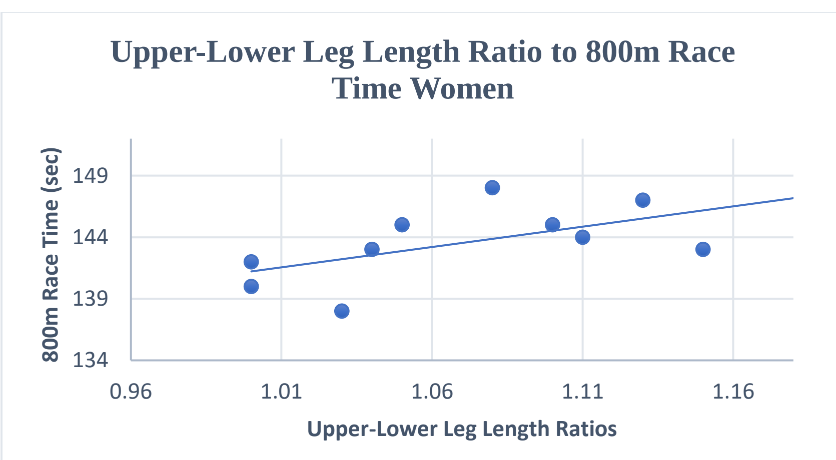
Female Runners

There were no correlations of significance found between a runner's thigh-calf girth ratio and their race performances over 800-5000m. Pearson r for the distances are as follows: 800m $r = 0.03$, $p > 0.05$, 1500m $r = -0.07$, $p > 0.05$, 3000m $r = -0.08$, $p > 0.05$, 5000m $r = 0.03$, $p > 0.05$.

Similar to the male subjects, the female runners of this study had significant moderate correlations between upper-lower leg length ratio and 800m race performances. $r = 0.58$, $r^2 = 0.34$, $p < 0.05$ (Graph 7, pg. 27). Borderline significant correlations were found between a runner's upper-lower leg length ratio and 1500m, 3000m, and 5000m race performance,1500m $r = 0.40$, $p > 0.10$, 3000m $r = 0.36$, $p > 0.10$, 5000m $r = 0.48$, $p > 0.05$. Borderline significance was also found between Lower leg length and 3000m performances, $r = -0.52$, $p > 0.05$. Unlike the male subjects, the females did not have the same significant correlations when thigh and calf girth measurements were added together (thigh+calf girths), $r = -0.32$, $p > 0.10$, or when the sums of thigh and calf divided by the sums of upper and lower leg lengths [(thigh+calf girths)/(upper+lower leg lengths)], $r = -0.39$, $p > 0.10$.

No other correlations of significance were found between any anthropometric measurements of female runners and their race performances over 800-5000m. Correlations were found, similar to the male subjects of the study, between various race performance distances, however they were not the purpose of the study (Table 6, pg. 28).

Graph 7: Female Upper-Lower Leg Length Ratio to 800m Race Performance



$r = 0.58$, $r^2 = 0.34$, $p < 0.05$

Table 6: Race time correlations based on other distance race times of female subjects

	800m	1500m	3000m	5000m
800m	N/A	800m-1500m r = 0.57 p < 0.05†	800m-3000m r = 0.65 p < 0.05†	800m-5000m r = 0.31 p > 0.05
1500m	800m-1500m r = 0.57 p < 0.05†	N/A	1500m-3000m r = 0.75 p < 0.01‡	1500m-5000m r = 0.81 p < 0.01‡
3000m	800m-3000m r = 0.65 p < 0.05†	1500m-3000m r = 0.75 p < 0.01‡	N/A	3000m-5000m r = 0.76 p < 0.01‡
5000m	800m-5000m r = 0.31 p > 0.05	1500m-5000m r = 0.81 p < 0.01‡	3000m-5000m r = 0.76 p < 0.01‡	N/A

† denotes statistically significant at $p < 0.05$

‡ denotes statistically significant at $p < 0.01$

Chapter 5 Discussion

For both the male and female subjects, there were significant correlations between a runner's upper-lower leg length ratio and their 800m race performance (Males $r = 0.60$, $r^2 = 0.36$ $p < 0.05$, Females $r = 0.58$, $r^2 = 0.34$ $p < 0.05$). H_0 is rejected for both males and females, with regard to the 800m distance. H_0 fails to reject for both males and females in the 1500m, 3000m, and 5000m distances. H_a is accepted for both male and female runners in the 800m distance. The correlation between both sexes show that runners with upper-lower leg length ratios closer to a 1:1 ratio perform better at the 800m. This correlation means that leg length ratios may be used to determine if a runner will perform better at the 800m, regardless of sex. For males and females, r^2 values were 0.36 and 0.34 respectively. The r values showed that 36% and 34% of race performance variability can be attributed to upper-lower leg length ratios, 64% and 66% of the other factors that influence performance according to other researchers comes from other factors such as physiological characteristics (running economy, muscle fiber type ratio, etc.), some other combination of anthropometric characteristics (limb length, skinfolds, etc.), or biomechanical influences (strides rate, stride length, foot strike pattern, etc.) (Conley, et al, 1980; Dellagrana, et al, 2015; Saunders, et al, 2004; Scholz, et al, 2008). In the female subjects, there were correlations that were not strong enough to be considered significant between upper-lower leg length ratios and all other races listed in the questionnaire (1500m, 3000m, 5000m) ($r = 0.41$, $r = 0.36$, $r = 0.48$, respectively), which may call for future studies to examine further. Previous studies support the present studies correlations. Previous studies have shown correlations that leg length in proportion to the upper body length is correlated with improved running economy and performance (Foster, et al, 2008; Lucia, et al, 2006). Proportional body length, and extremity lengths could be associated with improvements in running performance.

Several studies found correlations between a runner's race performances and the smallness of their lower extremities (Foster, et al, 2008; Laumets, et al, 2017; Tanaka & Matsuura 1981). Successful African runners had smaller thigh and calf structures when compared to their American counterparts (Pedoe, 2000). The present study found correlations that supports previous research. Strong correlations were found between a male runner's thigh girth and their 5000m race times ($r = 0.74$, $r^2 = 0.55$, $p < 0.01$). Correlations were also found between a male runner's calf girth and their 5000m race times, however it was only a moderate correlation ($r = 0.57$, $r^2 = 0.33$ $p < 0.05$). This is consistent with the conclusions of other studies referenced in the review of literature involving leg anthropometric measurements, that slim legs are common characteristics of successful long-distance runners (Bale, et al, 1985; Bale, et al, 1986; Barnes, et al, 2014; Foster, et al, 2008; Lucia, et al, 2006; Tanaka & Matsuura 1981). A previous study on elite Kenyan distance runners concluded that lower leg mass produced a lower moment of inertia, thus requiring less muscular effort to swing their legs when running. Thus, slim limbs in distance runners have been correlated with improved running economy and running performance. (Kong & Heer, 2008). Type I muscle fibers have more oxidative capacity and are smaller in size than type IIa and IIb muscle fibers. (Van Wessel, et al., 2010). Successful distance runners have higher type I muscle fiber ratios to type II muscle fibers. Slim limbs, which are correlated with successful distance running can be correlated with type I muscle fibers. The runners of this study who have slim limbs and faster 5000m PR's should have more type I muscle fibers than type II muscle fibers. It is also expected that those runners should have a superior running economy to other 5000m runners in the sample group.

A combination of anthropometric measurements was recommended by previous studies (Barnes, et al, 1985; Foster, et al, 2008). Thigh and calf girth measurements were taken and combined to create a thigh+calf measurement. Male subjects showed significant correlations between 5000m race performance and thigh+calf measurements ($r = 0.73$, $r^2 = 0.53$, $p < 0.01$). The smaller the total leg girth measurement 5000m race times were faster. Leg girths and leg lengths were combined into the following measurement: [(thigh+calf girths)/(upper+lower leg lengths)], a significant correlation was shown between this measurement and 5000m race performance in males as well ($r = 0.69$, $r^2 = 0.48$, $p < 0.01$). Runners with smaller total leg girths and longer total leg lengths had faster 5000m race times. These new combinations of measurements are consistent with previous research, that runners with slim leg girths and longer leg lengths perform better at distance running events (Bale, et al, 1985; Bale, et al, 1986; Foster, et al, 2008; Kong & Heer 2008).

There was a correlation for the lower leg length of the male subjects and their race performances in the 800m ($r = -0.51$, $r^2 = 0.26$, $p > 0.05$) (Graph 6, pg. 25), however this was not considered significant. For female subjects, a similar correlation was found with lower leg length and 3000m race times ($r = -0.52$, $p > 0.05$), but this was not considered significant as well. Laumets et al. (2017) study showed that leg length and running economy have an inverse relationship (improved running economy, when lower leg length was shorter) The present study contradicts previous research, as running performance in the 800m was better when lower leg lengths were longer. Although the present study did not look into running economy, it did find a correlation between a runner's lower leg length and performance. Previous research only measured running economy, which is run at much slower speeds than a trained runners 800m and 3000m race pace. Laumets study, while similar, was measuring different variables than the present study. Running form, and running economy vary when running at different speeds. This could account for the differences in results on leg length and performance. Running economy is considered one of the best predictors in race performance, the present study only evaluated previous race performances and not direct metabolic measurements, unlike Laumets study. The Lucia, et al, (2006) study on Eritrean runners supports the present study, they found that longer lower leg length as well as small calf circumference is associated with superior running economy, which is consistent with the present study's findings.

While not the goal of the study, tables 5 and 6 (pgs. 27 & 29) have several moderate to strong correlations between various race distances. The sample, for both males and females had correlations between 800m-1500m, 800m-3000m, 1500m-3000m, 1500m-5000m, and 3000m-5000m, which could be used to predict race performances at other race distances within this sampled population. Race times in other events can be used to predict race performance in another distance event, a regression equation was not created because that was not the goal of this study.

Practical Implications

The findings of this study can have practical uses for coaches and athletes. For example, one finding of this study was that the smaller the circumference of a male runner's thigh and/or calf, the faster their personal best performance is in the 5000m. This does not mean that the small leg circumference measurements cause the faster performances, rather a general trend in successful 5000m runners is smaller thigh and/or calf circumference measurements. The r^2 values for the male subjects' thigh, calf, thigh+calf, and thigh+calf/upper+lower measurements were, 0.55, 0.33, 0.53, and 0.48 respectively. Between 33%-55% of performance in the 5000m can be explained by leg anthropometrics. Race performance can be attributed to other factors as well, such as VO_{2max} or running economy, which have been shown to be two of the best indicators of race performance (Barnes, et al, 1985; Conley & Krahenbuhl, 1980; Scholz, et al, 2008; Saunders, et al, 2004). Running economy can have various other influences such as anthropometrics of the athlete, or other biomechanical influences (Saunders, et al, 2004; Scholz, et al, 2008). However, when a coach and athlete are deciding on which race distance to specialize their training towards, they can use thigh and calf girth measurements to help determine at what event they may best excel. More in particular, this can be used to determine if the 5000m race distance is a better option. If it has been determined that the athlete should focus training towards longer distance races, such as the 5000m, then training plans can be modified to emphasize the athletes' aerobic system. 5000m race training would involve a larger volume of training load to be dedicated towards aerobic training. Most studies agree that the 5000m race involves mostly aerobic energy system pathways, around 88%, while the remaining 12% of the energy provided comes from anaerobic pathways (Baker, McCormick & Robergs, 2010; Gastin, 2001). Also noted is that 800m race distance is typically 66% aerobic, 34% anaerobic. Both studies agree that the 50/50 aerobic/anaerobic crossover occurs between 1 and 2 minutes and most likely around 75 seconds. Emphasis on aerobic development would prove beneficial to the 5000m athletes' performance.

The same can be said for the other significant finding of this study, that in both males and females, the smaller the discrepancy in upper-lower leg length the better a runner's personal best performance is in the 800m. The sample size gathered had a range of 1.00-1.10 U-L leg length ratio for men and 1.00-1.15 U-L leg length ratios for women. Coaches and athletes can measure upper and lower leg lengths and calculate their ratios in order to determine if they are best suited for racing the 800m or not. Design of 800m race training involves a large aerobic element (66%

aerobic, 34% anaerobic), but more emphasis should be put on anaerobic energy system development as compared to the 5000m training (Gastin, 2001).

Treadmill running has been used to determine physiological characteristics of runners (running economy and anaerobic threshold most in particular) however, such equipment may not be readily available to all coaches or athletes. Running economy and anaerobic threshold have been used for years as reliable sources of race performance capabilities (Barnes, et al, 2014; Foster, et al, 2008; Lucia, et al, 2006; Millet, et al, 2002; Paavolainen, et al, 1985; Tanaka & Matsuura 1981). Due to the lack of availability of such equipment the present study can be used as a potential source of easy assessment of a runner's ability to perform at a certain distance race.

Limitations of the Present Study

The present study had several limitations. The sample size was only 23 subjects (12 males, 11 females). This sample size only came from one university, multiple universities being tested could have offered a larger sample size and more accurate data. The equipment was limited to only an inelastic Gulick measuring tape. The measuring tape can only be accurate up to the nearest tenth (0.1 cm) centimeter. Only anthropometric measurements were taken on subjects. Previous studies gathered physiological and biomechanical data on subjects.

Recommendations for Future Studies

Further studies should consider collecting data on a larger sample population, perhaps with multiple universities included. Different levels of track athletes could be included, for example, professional athletes, NCAA Division II or III, or high school athletes could be sampled. Including university athletes with a wider range or race performances should be included in further studies. Equipment that can collect physiological and biomechanical measurements on subjects, for example a DEXA scanner, or treadmill testing. Leg length in proportion to the upper body (torso) length should also be studied further, several other studies include proportional length of the upper and lower body. Future studies could also segment the upper and lower body ratios further, for example, the upper body in relation to the upper leg length only or the lower leg length.

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Appendices

Appendix A:

Athlete Questionnaire

Please record your personal records (Fastest time achieved to date) in the spaces below. If you have not run this event leave it blank. Only open race times will be accepted (no relays splits).

800m: ____________________ (mm:ss.ms)   1500m:____________________(mm:ss.ms)

3000m: ____________________(mm:ss.ms)   5000m:____________________(mm:ss.ms)

Are you… (Male or Female) circle one

Have you been completing your full training load (as prescribed by your coach) for one month?

(yes or no)

For official use only

Thigh:________________   Upper:____________________

Calf:__________________   Lower:____________________

Thigh-Calf ratio:____________   Upper-Lower ratio:__________

Appendix B:

INFORMED CONSENT

Dear Participant:

My name is Clay Dixon and I am a graduate student at Morehead State University in the Department of Kinesiology. I am requesting your assistance with a research project I am conducting on Thigh and calf girth, and upper and lower leg length. Let me emphasize that you do not have to participate. If you do not wish to take part in the survey or measurements, you do not have to answer any of the questions or participate. Completing this survey and measurement is voluntary and you may withdraw from the study at any time.

You must be 18 years of age or older to participate. You will need to show a photo I.D. to confirm you are over the age of 18 years. This study has been reviewed to determine that participants' rights are safeguarded and there appears to be minimal risk or discomfort associated with the completion of the survey and measurements. You may choose to discontinue your participation at any time. You may also skip any questions you do not wish to answer. Also, you need to understand that participating or not participating in the survey or measurements has no impact on your grade in this or any other class. Your decision to volunteer to complete the survey and measurements cannot hurt or help your grade. If extra credit is offered to those participating in the study and you do not wish to participate or are under the age of 18, an alternative method of extra credit will be offered.

The answers you provide will be kept strictly confidential and all research subject responses (completed survey, audio tapes, and video tapes) will be stored in a locked filing cabinet, accessible only to the researcher, inside a secure university building. Please feel free to ask for help if something does not make sense to you or if you have any questions. If you experience any discomfort, you may contact Clay Dixon by phone at 859-513-0451

If you decide to volunteer, please be sure to **PRINT YOUR NAME** on the form and **SIGN** it to indicate your willingness to participate. That will be our indication that you understand the purpose of the survey and that you are willing to help.

NAME *(please print)*:

____

Signature:

____

If you have any questions or concerns, you may contact the researcher:

Clay Dixon Laughlin Health Building 212

Cellphone: 859-513-0451 Email: m1069111@moreheadstate.edu